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DEVELOPMENT OF WINDOWLESS LIQUID LITHIUM TARGETS FOR FRAGMENTATION AND FISSION OF 400-kW URANIUM BEAMS

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Abstract

The driver linac of the proposed RIA facility is designed to deliver 2 x 10^{13} uranium ions per second at 400 MeV/u on target for radionuclide production via the fission and fragmentation mechanisms. The ion optics of the large acceptance, high resolution fragment separators that follow the production target require primary beam spot widths of 1 mm. To cope with the resulting high power densities, windowless liquid lithium targets are being developed. The present designs build on exisitng experience with liquid lithium and liquid sodium systems that have been used for fusion and fission applications. However, no completely windowless systems have been developed or tested to date. For the beam power indicated above (400 kW), the flow requirements are up to about 20 m/s and 10 liters/s linear and volume flow rates, respectively. The required target thickness is 1-1.5 g/cm2 (2-3 cm lithium thickness). At this time a prototype windowless system with a lithium thickness of 1-2 cm is under construction. The prototype will be operated initially without beam in the Argonne liquid lithium test facility. The details of the design of the prototype and a progress report on its construction and testing will be presented.

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1. Introduction

There are currently three large radioactive beam facilities around the world, either under construction [1] or being proposed [2,3], that would use high energy, high intensity uranium beams for in-flight production of fission fragments. All of these facilities will use large acceptance, high-resolution fragment separators following the production targets [4-6]. The optical designs of the fragment separators require beam spot widths on-target in the 1-mm range to enable high selectivity in the separation and purification of the secondary beams. For the continuous beams of the RIKEN RI Factory and the Rare Isotope Accelerator (RIA), the combination of uranium beams at high intensity and small beam spots requires production targets that can tolerate very high power densities, as high as several megawatts per cubic centimeter. The power densities are even higher for the pulsed beams of the GSI Future Facility [7]. Projectile-fragmentation targets based on rotating wheels of graphite are being developed at RIKEN [4]. This paper summarizes the on-going development of windowless liquid lithium targets being carried out at Argonne for the RIA project. The goal of this work is to develop a fragmentation target that can easily work with uranium beams at least up to 100 kW and preferably up to 400 kW, the design limit of RIA.

2. Concept for the windowless target

An earlier report that gave a preliminary design of a windowless liquid-lithium target for heavy-ion fragmentation at high beam power was presented at the conference RNB2000 [8]. A schematic layout of the proposed concept is shown in Fig. 1 and the performance goals for the target are listed in Table I. The beam-spot width is limited to 1 mm due to the optical requirements of the fragment separator. The target thickness is set by matching the energy loss of the beam to the acceptance of the fragment separator.

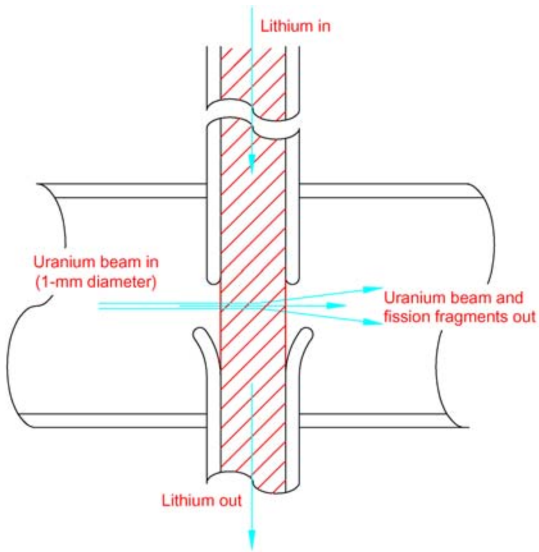

Fig. 1. Schematic layout of the concept of a windowless liquid lithium target for in-flight fission or fragmentation of heavy ions up to uranium, designed to work with beam power as high as 400 kW.

Table I. Target requirements for uranium beam.

Beam energy:	400 MeV/u
Beam power:	400 kW
Beam diameter:	1 mm
Target thickness:	1.5 g/cm^2

Table II. Thermal properties of the target.

Beam energy deposited:	120 kW
Power density at no flow:	4 MW/cm^3
Power density at 20 m/s:	200 W/ cm^3
Hot-spot temperature:	300 C
Maximum lithium vapor pressure	10^{-6} T

3. Thermal calculations for the full power RIA target

For a 400 MeV per nucleon uranium beam at a power of 400 kW the power density in lithium is 4 MW/cm^3, as indicated in Table II. For a graphite or beryllium target this would be about 15 MW/cm^3 due to their higher densities. With the lithium flowing at 20 m/s the power density is reduced by a factor of 20,000 keeping the maximum temperature below 300 C and the vapor pressure of the lithium at the hot spot below 10^{-6} T. For a nozzle cross section 1.5-cm wide by 3-cm long the total volume flow rate would be 9 liters/s and the averge temperature rise would be 6 C.

4. Pressure/flow requirements and pump design for a prototype target

As a first step towards the design and construction of the full-sized windowless liquid-lithium target for RIA, a scaled-down prototype has been designed and is currently under construction. The prototype will have a thickness in the range of 1-2 cm and have a flow rate of 5-10 m/s. Goals of this prototype project are to evaluate the lithium flow properties for a variety of nozzle types and to check the performance of our permanent magnet liquid metal pump designs. A drawing of the first nozzle to be tried is shown in Fig. 2. It is rectangular at the output end to increase the target thickness while minimizing the lithium volume flow-rate required.

A DC, permanent magnet Lorenz-force type of pump was chosen for this liquid-lithium loop. It is a larger version of the pump designed for the hybrid beryllium/lithium target described in a companion paper at this conference [9]. To achieve the higher volume flow rate at the correspondingly larger pressure drop required for the windowless target a rectangular pump duct is being used. A sketch of the pump duct and its corresponding equivalent electrical circuit is shown in Fig. 3. A photograph of the pump duct is shown in Fig. 4. The stainless steel duct was fabricated via a wire electric-discharge-machining process from a solid metal block to avoid possible problems with cracking and corrosion in weldments that have been experienced previously in pumps with cold-worked ducts [10].

Fig. 2. A section view of the tapered nozzle to be used in the prototype liquid-lithium target. It is rectangular, 10 mm by 5 mm, on the output and circular, 22 mm in diameter, on the input.

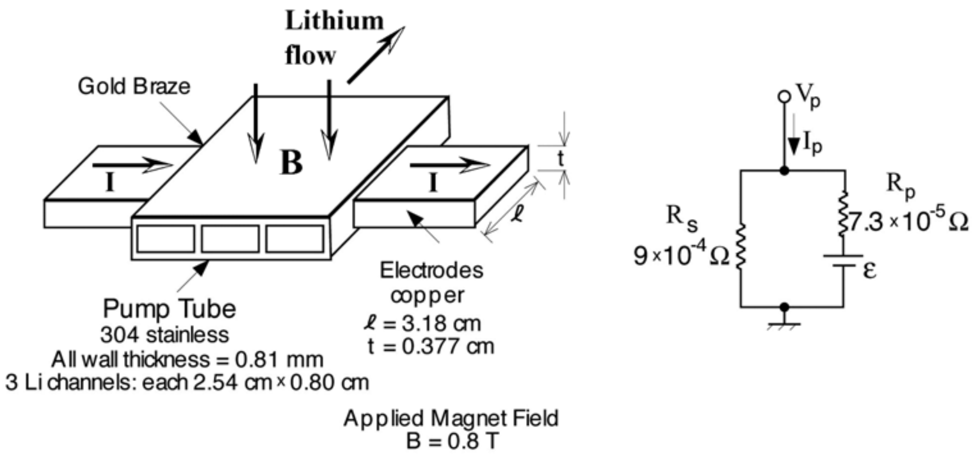

Fig. 3. Sketch of the DC permanent magnet pump concept and the equivalent electrical circuit of the pump duct.

Fig. 4. Photograph of the pump duct and current electrodes for the prototype target.

The pump duct and plumbing of the liquid lithium loop are designed such that the pressure drops on these components are small relative to that at the pump nozzle. For the pump duct dimensions shown in Fig. 3 and nominally 5-cm piping, the pressure overall pressure drop of the system is calculated to be 30,000 Pa at 10 m/s nozzle velocity. With 0.75 T magnetic field the required pump current is 391 amperes at 71 mV. The total pump power is 28 watts, with 53% of this going into pumping lithium and the rest dissipated in the pump duct resistance.

5. Mechanical layout

A mechanical drawing of the liquid lithium loop is shown in Fig. 5. The lithium flows from the nozzle which is just above the center line of a standard 15-cm conflate vacuum cross. There are clamp-on heaters and thermal insulation added to what is shown in the drawing. A photograph of the partially assembled system is shown in Fig. 6.

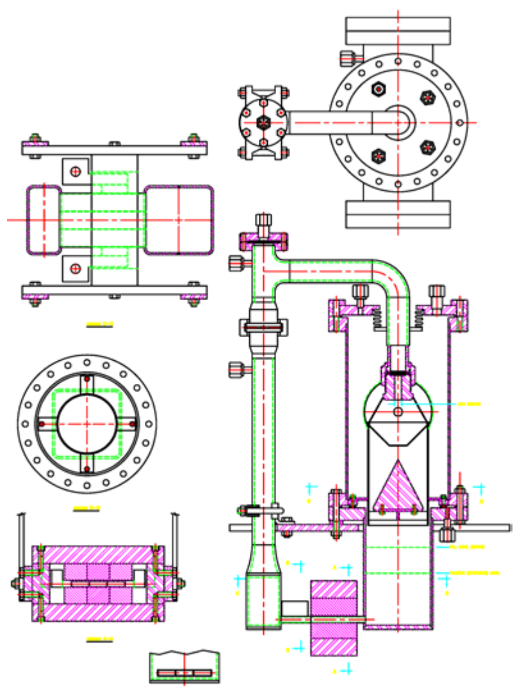

Fig. 5. Mechanical drawing of the liquid lithium target loop. The overall height of the loop is 0.6 m. A section view of the permanent magnet pump is shown at the lower left.

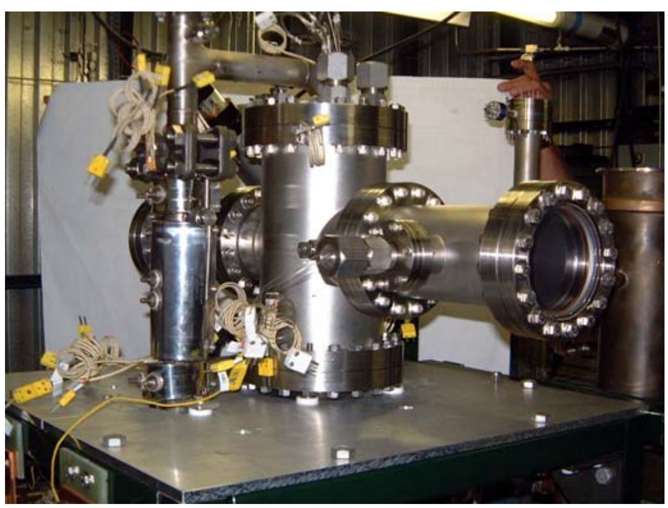

Fig. 6. A photograph of the partially assembly target system.

6. Safety issues and procedures

A general discussion of the safety procedures that are used for working with alkali-metal systems was given in [8]. Specific procedures have been written for the safe operation of the present system for initial testing within the existing liquid lithium laboratory at Argonne. These include a general safety document [11], a document of procedures for initial commissioning and operation of the loop [12], and a procedure to be followed for loading of the lithium into the pump loop [13].

7. Construction and testing schedule

The mechanical and electrical components of this prototype system have been fabricated and/or procured. The assembly will be completed during the summer of 2002. The vacuum system will be leak checked after assembly and the heaters and their controllers installed and debugged prior to loading the lithium. The lithium will be loaded under an argon atmosphere and the loop will be initially operated at atmospheric pressure with argon before commissioning under vacuum. Operation of the complete system with the first nozzle (5 mm by 10 mm) is scheduled to begin by September, 2002. This will permit evaluation of the pump design and flow characteristics relative to the design parameters, as well as, the observation of the uniformity and stability of the lithium jet as a function of flow velocity. Alternative nozzle designs may be evaluated depending on the results of these initial observations.

Assuming successful commissioning of the windowless target off-line as described above, the next steps will be to design and incorporate a heat exchanger capable of removing up to 10 kW of beam power from this 1-cm thick target. A near-term goal is to demonstrate operation of the system on-line at high beam power at an appropriate accelerator facility, possibly during 2003.

The full-scale RIA liquid-lithium target requires scaling this prototype up by a factor of 3 in thickness and a factor of 2 in velocity. After the addition of the heat exchanger described above, the only additional sub-system to be incorporated for long-term operation at high intensity will be one for impurity control. Impurity control traps, both hot and cold, have been developed as part of the inertial fusion materials irradiation developments [14]. These methods have been shown to provide for control of radioactive impurities such as tritium and ^{7}Be, as well as, carbon, nitrogen, and oxygen.

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